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Survival and Cause-Specific Mortality of White-Tailed Deer (*Odocoileus virginianus*) Neonates in a Southeastern Kentucky Population

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SURVIVAL AND CAUSE-SPECIFIC MORTALITY OF WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) NEONATES IN A SOUTHEASTERN KENTUCKY POPULATION

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Agriculture, Food and Environment at the University of Kentucky

By

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Lexington, Kentucky

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2017

ABSTRACT OF THESIS

SURVIVAL AND CAUSE-SPECIFIC MORTALITY OF WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) NEONATES IN A SOUTHEASTERN KENTUCKY POPULATION

Maintaining desired numbers of wildlife species requires an understanding of species-specific population dynamics. For ungulate species such as the white-tailed deer (*Odocoileus virginianus*), understanding the neonatal survival rate of a population and factors that influence that survival rate, may be two of the most important factors to successful deer management. We examined neonatal survival in an eastern Kentucky population of deer living in relatively low densities (<10 deer/ km^2), with adequate habitat and supposedly poor population growth. Neonates (102) were captured in the summer birth periods of 2014 - 2016 and radio-monitored until the beginning of the fall archery deer season. We found moderate-to-low survival estimates to four months of 43% (95% CI: 29 – 57%) that are consistent with many areas in the Midwest and southeastern United States. Predation, including suspected predation events, from bobcats (*Lynx rufus*) and coyotes (*Canis latrans*) accounted for 80% of all neonate mortalities. A thorough examination of the survival and mortality in the neonate component of this population is discussed herein.

KEYWORDS: White-tailed Deer, Fawn Survival, Cause-Specific Mortality, Predation, *Odocoileus virginianus*, Kentucky

Joseph R. McDermott

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Introduction

Large mammals can be keystone species whose impacts on community structure play a disproportionally large role for their abundance (Noss 2001). Large mammals determine ecosystem structure, function and composition, and fluctuations in their numbers have pronounced effects on ecosystems (Mech 1966, Woolf and Roseberry 1998, Ripple et al. 2001, Seward et al. 2004). Many large mammal species have experienced extirpation from portions of their historical range. Factors such as body size, low reproductive potential, and low genetic diversity have all contributed to population declines. Anthropogenic forces including overexploitation, non-native species introductions, and habitat loss and fragmentation (Diamond et al. 1989) have influenced these extirpations.

Although there are many species that still face significant risks of extinction (especially avian and herpetofaunal species), many species of wildlife have rebounded following a paradigm shift in thinking that occurred in the early twentieth century in North America. With wildlife receiving protection from the Lacey Act (16 U.S.C. §§ 3371–3378), and other new federal and state laws, and the advent of the Federal Aid in Wildlife Restoration Act of 1937 (commonly known as the Pittman-Robertson act), state fish and wildlife agencies had the legislative protection and funds to restore native populations to sustainable levels and reintroduce species that had been extirpated from the landscape. Black bears (*Ursus americanus* [Unger 2007, Murphy et al. 2015]), elk (*Cervus canadensis* [Maehr et al. 1999]), gray wolves (*Canis lupus*; [Bangs and Fritts 1996]), river otters (*Lontra canadensis* [Raesly 2001]), and bighorn sheep (*Ovis canadensis*; [Singer et al. 2000]) have all benefitted from restoration efforts. But perhaps

the greatest reintroduction success story in the history of wildlife management is that of the white-tailed deer (*Odocoileus virginianus*) (Adams and Hamilton 2011).

White-tailed Deer Restoration Efforts

White-tailed deer (hereafter, deer) populations reached an all-time population low around the turn of the nineteenth century with approximately 300,000 remaining in North America (Downing 1987). European overexploitation of deer, coupled with severe habitat degradation and lax game laws caused the greatest period of deer population decline (McDonald et al. 2004) and range reduction, resulting in some deer subspecies becoming endangered. Passage and enforcement of wildlife laws, as well as establishment of protected areas such as national parks and forests, facilitated deer recovery (Adams and Hamilton 2011). Many state wildlife agencies conducted extensive deer trapping and relocation efforts (~46,000 total deer moved) between the 1930's and 1950's that repatriated the species to portions of its former range (McDonald et al. 2004, Adams and Hamilton 2011). Despite these measures, many southeastern states did not experience the desired amount of growth in their deer populations after initial reintroduction efforts, thus leading to additional restocking efforts from 1980-2000 (McDonald et al. 2004).

Population Dynamics

Maintaining desired population levels requires an understanding of species-specific population dynamics (Gaillard et al. 1998, Plumptre 2000, Menu et al. 2002). Population studies of ungulates often focus on female adults and neonates because of their relative importance to population growth when compared to other demographic

groups (Gaillard et al. 1998). Previous studies have used radio-telemetry to determine age-specific survival rates (Seward et al. 2003, DeCesare et al. 2012).

Age-specific survival estimates of deer fawns are presented for a variety of times that depend upon on research interests or through necessity (i.e. low sample sizes, high rates of mortality events or censors, all of which can influence confidence limits and detection power [DeYoung 2011]). The most commonly reported age-specific survival estimates have been determined based on physical abilities (relative mobility), behavior related to food source (e.g. nursing vs. weaned), predation risk, and the structure or timing of the annual deer hunting season. Fawn survival has been studied in the following time blocks: 1) birth to 4 weeks (Huegel et al. 1985), 2) birth to 8 (Carroll and Brown 1977) or 9 weeks (Vreeland 2002, Brinkman et al. 2004), 3) birth to 4 (Kilgo et al. 2012) or 6 months (Hiller et al. 2008), 4) birth to 9 months (Vreeland et al. 2004), and 5) birth to 1 year (Ballard et al. 1999). Survival to each subsequent time period frequently increases the likelihood of survival to recruitment and adulthood.

Recruitment is a useful concept in population studies because it is measured when the young are at an age of importance to the population and is often represented as a rate (McCullough 1984). Recruitment rate is defined as the number of recruits per individual in the population producing the recruits (McCullough (1984), often presented as a fawns/doe ratio (Allen et al. 1997). In most every circumstance, annual recruitment must equal adult mortality for a deer population to persist (Whittaker and Lindzey 1999). When deer fawns are the focal point of the study, the time at which an animal is "recruited" into the population depends on the specific goal of the researcher. Fawn recruitment is often described as having occurred when the animal reaches one of two

junctures: 1) the start of the fall hunting season (Kilgo et al. 2012; Robinson et al. 2014), or 2) one year of age (Wood et al. 1989).

Survival to the start of the hunting season is an important measure of recruitment in deer because fawns are legal animals to harvest and survival begins to resemble that of an adult deer with less mortality attributed to natural causes (DeYoung 2011). This period varies regionally depending on the timing of the statewide deer hunting season. Recruitment estimates to the start of hunting season may vary in length from four to six months. Most states, including Kentucky, have an archery season that begins around the start of September and fawns are legal animals to harvest so it is more critical to report a four-month estimate if the goal is to represent the number of fawns that reach harvestable age (Kilgo et al. 2012). Six-month survival estimates largely coincide with the beginning of a modern firearm season, which is when the majority of hunters are in the woods and the greatest period of hunter harvest often occurs (G. Jenkins, KDFWR, personal communication). At six months, fawns also may be capable of reproduction if sufficient food quality is available (Barber 1984). It is estimated that between 70 and 80 percent of deer fawns and nearly all yearlings can be bred provided they receive ample nutrition (Nixon and Etter 1995). As discussed above, however, recruitment to four months may prove more logical than six months in areas such as Kentucky with a fall archery hunting season.

Recruitment measured at the one year mark is noteworthy because all female deer reach sexual maturity at this age and can add to the next cohort of fawns (Barber 1984), and is also a measure of net annual production, deemed reproductive recruitment. However, it is oftentimes difficult to generate survival estimates to reproductive age for

two primary reasons. First, many of the modern collar developers offer expandable neonate collars with a field life of no greater than 9 months. Second, survival estimates reproductive age would require large sample sizes and/or collar retention rates to counterbalance the high number of mortalities and censor events faced by many researchers (Grovenburg et al. 2014).

As important as measures of recruitment are to understanding and managing populations successfully, survival estimates at shorter time intervals can also be beneficial to wildlife managers, particularly in terms of understanding periods of heavy mortality that may influence recruitment. Most fawn mortality occurs in the initial 8 weeks of life. Eight-week survival is important to deer managers because fawns are weaned at approximately 8-9 weeks of age. Prior to weaning, fawns are largely scent-free (at least to humans) and rely on cryptic coloration to hide and avoid predation (Halls 1984). As fawns reach 1-2 weeks of age they become more mobile and begin to exhibit "play" behavior that has also been documented in other mammals (Spinka et al. 2001). Play-like behavior is important because fawns are moving from their hiding locations, which places them at a higher risk of detection, and makes their cryptic coloration and hiding life-history strategy less useful. During this time, fawns are completely dependent upon their mother for nourishment; the quality of this maternal care has been shown to influence survival, especially in landscapes lacking the risk of predation (Gaillard et al. 2000). Although milk may still comprise a small portion of their diet, weaned fawns meet most of their nutritional needs through browsing, the increase in which is concurrent with increased mobility. Huegel et al. (1985) noted a significant increase in survival post-

weaning as fawns become swift enough to evade most predators, which adds further validity to the use of an eight to nine-week survival estimate.

Cause-specific mortality studies are frequently used alongside survival studies (Kunkel and Mech 1994, Ricca et al. 2002) and focus on specific factors that influence the death of study animals. In most cause-specific mortality studies, researchers use telemetry to detect collared animals that die in sufficient time to determine a cause of death (Grovenburg et al. 2011). The collars have not been shown to influence mortality of ungulate neonates when used properly (Jon et al. 1999). Vreeland et al. (2004) stated that fawn mortality studies are very limited across the deer's range, but these studies can have profound management implications through altered harvest regulations (Gilbert and Raedeke 2004) or improved population model inputs (Ballard et al. 1999).

Proper deer management requires an understanding of fawn mortality patterns from birth to recruitment into the huntable population (Huegel et al. 1985). Factors most commonly associated with fawn mortalities include legal and illegal harvest, road kills, disease, malnutrition, and predator events (DeYoung 2011). Predation has been the leading source of mortality in many survival studies of ungulate neonates (Adams et al. 1995, Smith and Anderson 1996, Hiller et al. 2008), particularly in habitats dominated by closed canopy forests (Vreeland et al. 2004). Predator species previously identified as important sources of deer fawn predation include gray wolf (Kunkel and Mech 1994), black bear (Mathews and Porter 1988), bobcat (*Lynx rufus*) (Beale and Smith 1973), and coyote (*Canis latrans*) (Schrecengost et al. 2008). Based on the geographic distribution of these species, black bears, coyotes, and bobcats were expected to be the sources of

predation events in southeastern Kentucky, although feral dogs may also pose a risk (DeLime 1951).

Malnutrition and/or disease is often the next leading contributor to fawn mortality (Cook et al. 1971). Carroll and Brown (1977) found disease and malnutrition to be significant contributors to fawn mortality events. Gaillard et al. (2000) suggests that inadequate maternal nutrition during the gestational period can influence fawn malnutrition pre-weaning. Sams et al. (1996) claimed that maternal malnutrition leads to delayed lactation and weaker fawns that are unable to nurse. This could prove important as previous researchers suggested that southeastern Kentucky (at least in the past) had relatively poor habitat conditions that could lead to malnourished does producing weaker fawns (DeLime 1951).

Studies determining fawn mortality have been difficult to carry out in forested regions where fawns are hard to find (Carstensen et al. 2003). To facilitate fawn capture in these areas, researchers have recently begun to use vaginal implant transmitters (VITs). Bishop (2011) maintains that VIT use is the most promising technique employed to capture neonates from marked females. Swanson (2008) found no difference between survival of fawns captured using VITs and ground searches, and several researchers have shown dramatic increases in capture success rates when comparing the use of VITs to traditional ground searches. For instance, Carstensen et al. (2003) captured fawns 21% of the time while ground searching and 88% of the time when using VITs. Carstensen et al. (2003) also reported that it required 3.5 times additional effort to capture fawns through ground searches instead of using VITs. Bishop (2007) noted an 88% capture success rate

while using VITs compared to 30% success rate when monitoring collared female mule deer (*Odocoileus hemionus*) that were not inserted with VITs.

Kentucky Deer Restoration and Management

The Kentucky deer population once numbered as low as ~1,000 in the early 20th century (Gassett 2001). Between 1946 and 1951, 387 deer were trapped within the state and released on wildlife management areas (WMAs) throughout Kentucky (DeLime 1951). Deer recovery varied considerably across the state, but southeastern Kentucky fared worse than other areas due to poor habitat conditions, feral dogs (DeLime 1951), and illegal shooting of animals (Blackard 1971). Deer continued to be trapped and relocated within the state into the 1970's to help bolster local populations with slower recovery rates, but 300 Wisconsin founders were needed to offset poor growth in southeastern counties alone (Blackard 1971, KDFWR 1997). In 1984, the Kentucky Department of Fish and Wildlife Resources (KDFWR) began intrastate deer trapping and relocation to southeastern Kentucky to increase the regional population; an additional 500 deer were released during this effort that ended in 1999 when it was estimated that deer numbers were stable or increasing with at least 1000 deer/county (Gassett 2001).

KDFWR manages deer populations on a countywide basis using regulated hunting and a "zone system" as the preferred tool to manipulate populations to desired levels (G. Jenkins, KDFWR, personal communication). As of the 2015-2016 deer season, there were four different KY deer management zones (1-4) primarily based on estimated countywide deer densities and available habitat (G. Jenkins, KDFWR, personal communication). Statewide each hunter may only harvest one antlered deer regardless of

method (i.e. modern firearm, archery, muzzleloader, etc.; Table 1), so zone differences in regards to male harvest are minimal. Zone 1 and 2 counties occur in the more agricultural central and western portions of the state and have the highest deer densities and highest quality habitat. The primary management strategy in these areas is herd reduction (D. Yancy, KDFWR, personal communication) and the antlerless firearm harvest potential is high (3 weekends, 2 weeks; Table 1). Hunters in Zone 1 counties may harvest an unlimited number of antlerless deer throughout the hunting seasons if they purchase bonus antlerless-only tags. Zone 3 counties have lower deer densities with underutilized habitats and these are rural, forest-dominated landscapes characteristic of the southcentral portion of the state. Managers believe the habitat could sustain more deer, so antlerless firearm harvest is restricted through season length (2 weekends, 1 week; K. Sams, KDFWR, personal communication), but a Zone 3 hunter may harvest up to two antlerless deer (or an antlered and an antlerless) with a firearm. Zone 4 counties have the lowest deer densities in the state and are located throughout the southeastern counties in the rugged, Cumberland Plateau physiographic region. Zone 4 counties have the lowest available antlerless firearm harvest potential that is limited to youths under 15 hunting during a youth weekend, or the last three days of the December muzzleloader season (Table 1). No more than one antlerless deer may be taken with a firearm, but up to four may be taken with archery equipment. In 2012, Kentucky's average deer density was estimated at 21 deer/ mile^2, while the southeastern region had an average deer density of <10 deer/ mile^2 (G. Jenkins, KDFWR, unpublished data). Population estimates generated from harvest data suggest that deer in Zone 4 counties have regionally declined by 36%

since 2005, with poaching, predation, and poor mast identified as potential causes (G. Jenkins, KDFWR, personal communication).

Sale of large mammal hunting licenses (in particular, ungulates like deer and elk) economically underpin much of the income of state fish and wildlife agencies (Duda et al. 2010). In 2011, 10.2 million deer and elk hunters in the U.S. spent $1.2 billion dollars (Hewitt 2011). That same year hunters in Kentucky purchased > 300,000 hunting licenses (USFWS 2011) and spent an estimated $798 million pursuing game animals; 70% was spent on big game species, primarily deer and elk. Hunter satisfaction is often closely linked with seeing and having the opportunity to harvest game (Hammitt et al. 1990), with an increasing likelihood to spend money when perceived quality of target species increases (Balkan and Kahn 1988). Therefore, given the economic and cultural importance of deer and deer hunting to the state of Kentucky, and to inform management of deer populations, it is important to understand what factors influence short and longer-term population dynamics.

McCullough (1979) estimated that a white-tailed deer population could grow at a rate of up to 89% at low densities with good habitat, but deer populations in southeastern Kentucky that exist in those conditions have lagged for decades. Our research investigated potential reasons for the estimated population decline of white-tailed deer numbers in southeastern Kentucky where conservative Zone 4 harvest policies, intensive restocking, and abundant habitat appeared to be inadequate in facilitating population growth and maintenance of regional deer numbers at desired management levels. Our objectives were to: 1) estimate neonate survival at two biologically relevant periods, 2) determine cause-specific mortality, 3) characterize the relationship between body metrics

and survival, and 4) estimate recruitment through the fall hunting season. Given the suspected low deer density in this region of Kentucky, we hypothesized that deer neonate survival would be relatively low (< 25%) through the first 4 months post-parturition, and that wild (coyotes) and domestic (feral and free-roaming) canids would likely be the most important mortality factor for fawns.

Table 1. White-tailed deer hunting zones by season length, weapon types permitted, and female bag limits in Kentucky, USA during the 2015-2016 hunting season. Retrieved from 2015-2016 Kentucky Hunting Guide.

	Zone 1	Zone 2	Zone 3	Zone 4
Bag Limit	Unlimited	Up to 4	Up to 4	Up to 4
Modern Firearm	Nov. 14-29, 2015 (either sex)		Nov. 14-23, 2015 (either sex)	Nov. 14-23, 2015 (antlered only)
Archery	Sept. 5, 2015 – Jan. 18, 2016 (either sex)			Sept. 5, 2015 – Jan. 18, 2016 (either sex, except antlered only Oct. 17-18, Nov. 14-23 and Dec. 12-17)
Crossbow	Oct. 1-18 and Nov. 14 - Dec. 31, 2015 (either sex)			Oct. 1-18 and Nov. 14 – Dec. 31, 2015 (either sex, except antlered only Oct. 17-18, Nov. 14-23, Dec. 12-17)
Muzzleloader	Oct. 17-18 and Dec. 12-20, 2015 (either sex)			Oct. 17-18 and Dec. 12-17, 2015 (antlered only) and Dec. 18-20, 2015 (either sex)
Youth-only Firearms	Oct. 10-11, 2015 (either sex)			
Free Youth Weekend	Dec. 26-27, 2015 (either sex)			

Materials and Methods

Study Area

Research was conducted in Clay County, which is located within the Cumberland Plateau physiographic region of Kentucky. Clay County is predominantly rural, with a population of 21,013 people and a density of 17.2 people/ km^2 (Census Bureau 2015). Research was conducted in the eastern-most portion of the county, just west of the Clay and Leslie County line along state highway 66 (Figure 1). We used ArcGIS version 10.2 (ESRI. Redlands, CA) to create maps and the 2005 National Land Cover Database to estimate percent land cover types. The study area encompassed 148 km^2, most of which (59.5 %) lies within the limits of the Redbird Ranger District of the Daniel Boone National Forest. This area is characterized by steep, mountainous terrain and closed canopy, mixed-mesophytic forests with intermittent river bottoms in row crops or pasture. Percent land cover includes 82.1% forest, 11% pasture, 0.1% crops, 6.1% developed land, 0.4% open water, and 0.1% wetlands. Dominant tree species in the area were oaks (*Quercus sp.*), hickories (*Carya sp.*), ash (*Fraxinus sp.*), pines (*Pinus sp.*), yellow poplar (*Liriodendron tulipifera*), and American beech (*Fagus grandifolia*). Typical understory species include paw paw (*Asima triloba*), spice bush (*Lindera benzoin*), hophornbeam (*Ostrya virginiana*), and American hornbeam (*Carpinus caroliniana*). Dominant row crops were soybeans (*Glycine max*) and corn (*Zea mays*). Pastures were dominated by fescue (*Festuca sp.*) and clovers (*Trifolium sp.*).

Capture and Handling

As part of a parallel mortality study of female white-tailed deer, 89 adult does (≥ 0.5 years) were captured and collared with very high frequency (VHF) LMRT-2 radio collars (Lotek Wireless Inc., Newmarket, Ontario) during the 2014-2016 trapping seasons. Each trapping season was divided into two time periods ranging from approximately January 1- March 31 (winter), and then July 1- August 1 (summer); the former period was chosen to avoid potential injury to late term pregnancy does and fetuses, and the latter period used to supplement winter trapping and avoid baiting restrictions during the spring turkey hunting season. Any adult female (≥1.5 yrs) captured in the winter trapping season was fitted with a model M3930 vaginal implant transmitter (VIT) with a temperature sensitive switch from Advanced Telemetry Systems (Isanti, MN) (Bishop et al. 2011) that changes pulse rate when expulsed during parturition. The VIT insertion apparatus was 5/8 in PVC pipe cut into an 18-in section. We cut one end at an approximately 45-degree angle and sanded until smooth to facilitate insertion and prevent injury. We used a permanent marker to place hash marks at 1-cm intervals to record the depth of the vaginal canal on one side of the insertion tool. We used ¼-in diameter fuel hose cut to 24 in for the plunger. Both the insertion tool and the plunger were stored in a 2-in diameter section of PVC pipe with a hard cap on one end, and a screw off cap on the other. Both caps were primed, and then sealed in place with PVC cement. We filled approximately half the volume of the storage container with a diluted mixture of water and Nolvasan S (chlornexidine diacetate; Zoetis Inc., Kalamazoo, MI) to keep the equipment sterile.

Effort was made in 2014 to use an ultrasound device to check pregnancy of captured does (Carstensen et al. 2003) but the technique was unreliable and not utilized during the second or third years. Historic reproductive data from the region found that >85% of all females were pregnant by 1.5 yrs of age (G. Jenkins, KDFWR, unpublished data), so all captured females ≥1.5 yrs were inserted with a VIT, which is consistent with previous research (Kilgo et al. 2012, Chitwood et al. 2015). We collected a 10 mL blood sample from the jugular vein during the capture process. Blood was immediately (< 2 hrs) transported to the field station and centrifuged for 5 minutes. We extracted the resulting serum and froze it in cryovials until examination in a lab. We tested the serum for pregnancy-specific protein B (Biotracking, Inc., Moscow, ID) to avoid wasted time doing VIT telemetry sweeps of non-pregnant does. We monitored VITs once daily via ground telemetry beginning May 1 until we detected the first expulsed VIT. Monitoring then increased to 2-3 times daily to increase the likelihood of finding fawns near the birthing site (Carstensen et al. 2003). Upon detection of an expelled VIT, the field crew used homing ground telemetry to attempt to locate it 3 hrs after expulsion. This delay allowed time for the doe to give birth, clean, feed, and form a maternal bond with her young (Haskell et al. 2007), and to provide some consistency in the amount of time fawns were caught and weighed after birth (Saalfeld and Ditchkoff 2007).

We assumed twins were present in all does because we were unable to ascertain the number of fetuses each doe had with an ultrasound reading. If we failed to locate 2 fawns within the immediate vicinity of the birth site or VIT, we systematically searched the immediate area in a grid-like fashion until 2 fawns were recovered, or until we felt the area had been thoroughly exhausted. Due to the short amount of time post-parturition, we

expected the majority of fawns to be ≤ 100 m apart (Rongstad and McCabe 1984). If a second fawn was not located within 100 m, we increased the search area to 200-300 m (Cartensen et al. 2003) in concentric circles, or in the direction of the collared doe. In cases when this too failed, we left the area for 3-4 hrs to allow the doe time to come back and feed her fawns. We then used honing ground telemetry to locate the doe to attempt to catch her nursing the previously undetected fawn(s).

We attempted to capture fawns opportunistically by searching areas with high abundances of fawn rearing habitat types in between VIT telemetry checks (i.e. hay fields, forest openings, edge areas, etc.) (Ballard et al. 1999). Historic deer reproductive data in Kentucky indicated an annual peak fawning date on June 1 with the majority of fawns being born in the last week of May and the first week of June (G. Jenkins, KDFWR, unpublished data). We waited until the last week of May to begin targeted ground searches so there was a higher probability of finding fawns. We also used a handheld forward looking thermal imaging scope (FLIR Scout II, FLIR Systems Inc., Wilsonville, OR) at night in areas with high visibility (fields, pastures, etc.) (Ditchkoff et al. 2005). We attempted to walk in and find fawns when does were witnessed exhibiting post-parturition behavior. Field crews attempted to encircle bedded fawns to decrease the risk of flight (Ditchkoff et al. 2005). Because fawns are more difficult to capture with increasing age, we used a fish landing net to assist with some captures (Rongstad and McCabe 1984).

Once captured, we blindfolded fawns to reduce stress. We recorded body measurements (hind foot length, shoulder height, total body length, chest circumference, and head length), sex, and age based on VIT expulsion date, or new hoof growth indices

(Sams et al. 1996) for opportunistically captured individuals. We then placed fawns in a mesh bag and recorded body mass using a digital fish scale. Each fawn was fitted with one drab, inch long, metallic ear tag and a one inch, tan, button style plastic tag (National Band and Tag, Newport, KY) on opposing ears, and fitted with a SirTrack model V5C162F expandable neonate collar (SirTrack Limited, New Zealand) with a mortality switch that increased pulse rate when immobile for ≥ 4 hrs.

Prior studies have indicated a low risk of doe abandonment of fawns due to human handling (Powell et al. 2005), but we made an effort reduce human odors and presence at the scene. Fawn handling was limited to two people, although additional staff was usually present to assist in locating the fawns in thick cover. The two people that handled the fawn wore calving/artificial insemination gloves with nitrile gloves over the top. We moved fawns at least 30 m from their original hiding location to another site for the workup process and then returned them after it was completed. All capture and handling procedures were approved under University of Kentucky IACUC # 2013-1138**.**

Monitoring

We monitored fawns via ground telemetry 2-3x daily from birth to 8 weeks postpartum, because this period had the highest mortality rates in previous studies (Carroll and Brown 1977). If a fawn could not be located during ground telemetry sweeps over a 24-hr period, we used a fixed-wing Cessna 150 outfitted with two, directional, four element Yagi-style antennas to locate the fawn. Monitoring frequency decreased to 1-2x/week after the latest born fawn reached 8 weeks of age, and continued at this rate until the beginning of deer archery season.

We located fawns as quickly as possible upon detection of a mortality signal to increase the odds of finding an intact carcass or remains. When we detected a mortality signal, we recorded the time between mortality sweeps, the time from detection of a mortality signal to the start of the search, and the time from detection to carcass recovery. We attempted to determine a cause of death for all mortalities expected to be predation driven when possible by using the guidelines provided by White (1973), Mathews and Porter (1988), and Labisky and Boulay (1998). We examined carcasses grossly then skinned them to look for characteristic bite patterns on the neck, head, shoulders, and subcutaneous bruising which is indicative of a predation event. If predation had occurred, or we observed signs of scavenging, we used Q-tips to swab any remains that had a high likelihood of coming into contact with predator or scavenger saliva (e.g. pre-mortem bite wounds, ear tags, collars, etc.) (Kilgo et al. 2012) to provide further evidence to support our determination of cause of death. We placed swabs in a labeled dry coin envelope, stored them in an airtight container, and then shipped them at the end of each field season to the National Genomics Center for Wildlife and Fish Conservation in Missoula, MT for identification to the species level. The exact specifications of the mtDNA testing, including the mtDNA extraction and replication techniques, and analysis can be found in Kilgo et al. (2012). We only collected predator genetic samples for the 2014 and 2015 fawning seasons. We listed predation as the cause of death whenever we detected pre-mortem bite marks on a carcass. Suspected predation was listed if we were unable to definitively discern between mortality types due to lack of evidence at the scene (i.e. difficult to determine between abandonment [and subsequent scavenging] and predation when there is only chewed-up bone fragments, bits of hide and chewed collars). If gross

identification of mortality factors could not be made (i.e. an unmarked, intact carcass was found), carcasses were removed from the field and immediately transported to the University of Kentucky Veterinary Diagnostic Lab or the KDFWR veterinarian building for necropsy.

Survival Analysis

We used a multi-model analytical framework to examine the potential effects of fawn morphometrics, sex, maternal age and body mass on survival. We performed two rounds of analysis: the first to examine survival of fawns captured opportunistically and with the use of VITs (collectively, "all fawns"), and the second to examine maternal effects on survival of fawns with known mothers (collectively, "VIT fawns"). We used Akaike information criteria (AICc) model selection adjusted for small sample size criteria to select the best fitting model (Burnham et al. 2011). Covariates used in the model were determined a priori as potentially influencing survival. These included: weight at capture, hind foot length, (collectively, bigger fawns are thought to live longer), sex (males die more frequently), maternal age (determines hierarchy in social units [Haskell et al. 2008] and experience in selecting optimum fawn rearing habitat [VanMoorter et al. 2009]), and maternal weight (influences size, predation risk [Mech et al. 1991], and ability to nurse). We only used two of the fawn body metrics in our analysis to reduce the risk of multicollinearity between covariates and because both hind foot length and weight have been used to examine survival in other studies. We limited the maximum number of effects in the model to two given the relatively low sample size. To test whether or not the relationship between maternal age and fawn survival was quadratic, we also squared the maternal age of fawns caught from known-age females. We did not use the same

covariates for all fawns because it was inappropriate to include maternal effects for opportunistic fawns born to unknown females. We estimated hazard ratios for all covariates found to be significant and only models with ≥2 ΔAIC were considered as competitive models.

We used Cox proportional hazards (CPH) models with a staggered entry approach to estimate total fawning season survival and recruitment at four months of age in Program R using the multi-model inference package MuMin (Bartoń 2013) and base package survival (Therneau 2013). We selected the CPH model because it is a semi-parametric analysis that accounts for how many days individual fawns contribute to the study, Julian calendar date of birth (i.e. mortality risks aren't the same for fawns born at start as opposed to middle of fawning window), differences in age at capture, and independent covariates can also be added to help explain variance in survival estimates. The high number of censor events we recorded in the weeks following capture precluded estimating one-year survival, so we instead estimated survival at the onset of the fall hunting season (7 September) which provided wildlife managers in Kentucky with an estimate of recruitment into the huntable population. We used May 1 as a uniform start date (the hypothetical start of fawning season) and September 7 as the uniform recruitment date (corresponds with the start of the fall archery season) for fawns living through that period. We included individual fawns in the analysis on their date of capture. Individual fawns were right-censored in our survival analyses for any of the following three scenarios: 1) transmitter failure, 2) if the transmitter was found with no evidence of fawn (i.e. no remains, signs of scavenging, bite marks or blood on collar, etc.), or 3) if a fawn lived to be older than the time period in which survival was estimated. If a fawn that

was previously censored from the study was recaptured during an adult trapping season, that fawn's censor date was adjusted to September 7 of the year it was captured to provide the most accurate estimation of survival. This method has been criticized due to claims that it provides an altered survival estimate, especially when the opportunity to catch adults the following year is unavailable; however, recent findings indicate these critiques may be unfounded (DeCesare et al. 2016). We generated eight-week survival estimates to facilitate comparisons between studies using the baseline CPH models. Survival to eight weeks was estimated conditional upon the minimum, mean, and maximum birth dates to get a range of expected eight week survival estimates throughout the fawning season (Zabor et al. 2013). Because this is a newer method of estimating survival, we compared eight-week estimates of survival by comparing the confidence intervals as opposed to other methods used for determining the difference between survival curves (e.g. log-rank tests) (Davis et al. 1999, Zabor et al. 2013). We used likelihood ratio tests to compare four-month survival estimates between years and sex.

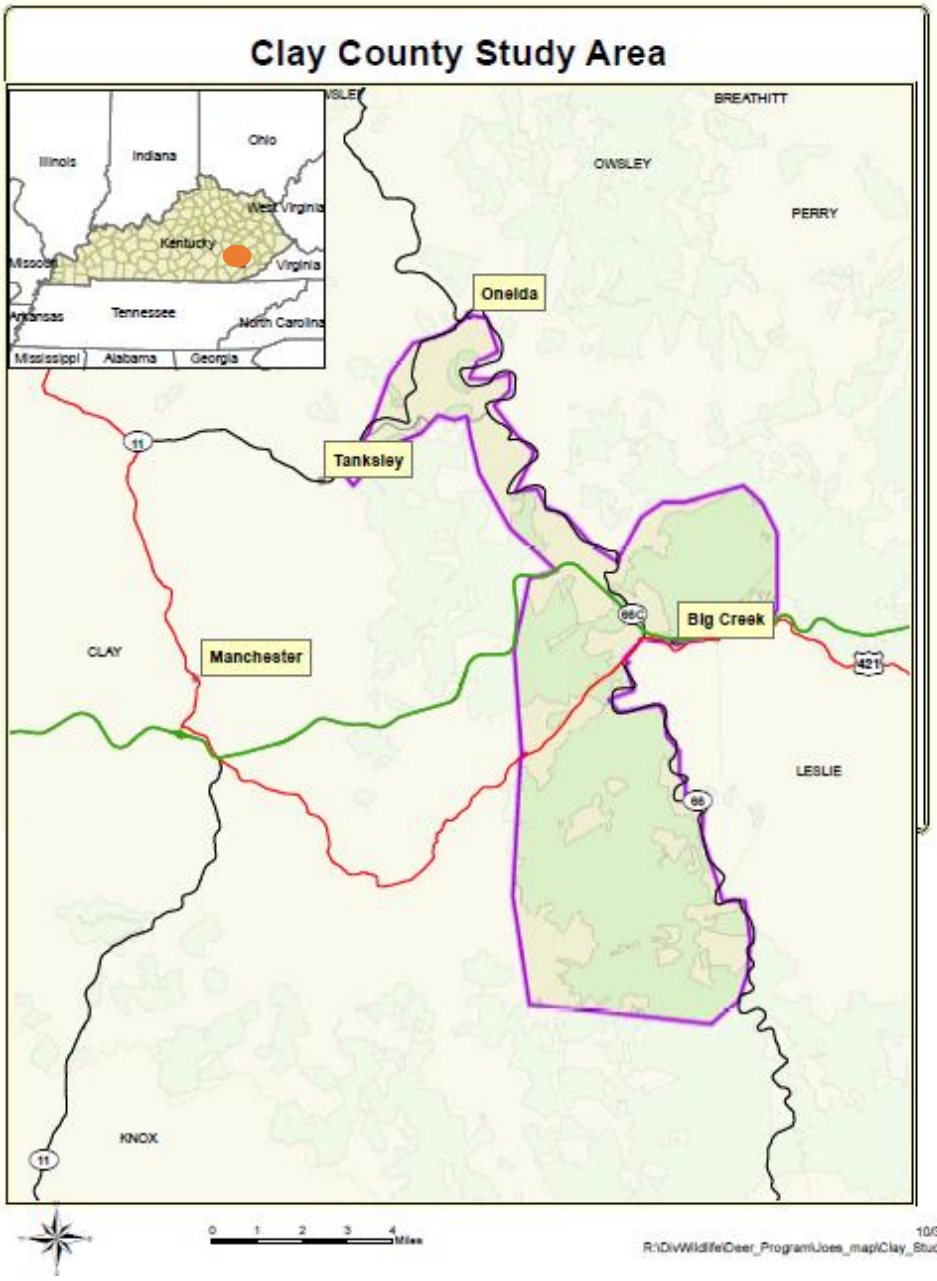

Figure 1. White-tailed deer fawn capture area located in the southeastern portion of Clay County, Kentucky, USA.

Results

Fawn Capture, Morphometrics, and Handling

We inserted 54 VITs during the 3 winter trapping seasons (2014 = 14, 2015 = 20, and 2016 = 20). Blood sample analyses indicated 50 of 54 (94.4%; 2014 = 1, 2015 = 3, 2016 = 0 non-pregnant) does inserted with VITs and aged ≥1.5 yrs were pregnant at the time of capture. One VIT was lost in 2014 due to a pre-partum vehicle collision, two VITs were lost due to a data collection error in 2015, one was lost in 2016 to a pre-partum vehicle collision, and one to early expulsion. The remaining 45 VITs were used to capture fawns and generate fawn/doe ratios regardless of whether or not fawns were physically recovered (i.e. just because fawns weren't captured, doesn't mean they weren't there). During the 2014-16 fawning seasons, 61 fawns were captured from 45 VIT-implanted does (2014 = 20 from 12 VITs, 2015 = 22 from 15 VITs, 2016 = 19 from 18 VITs) resulting in an average 1.36 fawns/ doe. We captured 43 males (2014 = 13, 2015 = 18, 2016 = 12) using VITs as opposed to just 18 females (2014 = 7, 2015 = 4, 2016 = 7; Table 2). The majority (84%) of VITs were found ≤ 15 m from the suspected birth site, but occasionally the distance was ≥ 100 m (n = 8) with one doe giving birth ~ 400 m from the location of the expulsed VIT. Average distance between the expulsed VIT and one or more fawns was 42.4 m. The average distance between twins was 13.6 m, but we did record a single instance of twins 100 m apart. Average fawn handling time was 13.6 minutes and average total time on site (measured from the time the VIT or first fawn was found until we released last fawn or gave up) was 31 minutes.

In addition to the fawns located with VITs, we opportunistically captured 41 fawns using a combination of evening thermal scans (n=1), observation of doe behavioral cues in open or edge areas (n=8), and targeted ground searches through probable fawning habitat (n=32). More males (26) were opportunistically captured than females (15) (Table 2). All opportunistic fawns were captured in river bottom pastures or fallow fields where habitat characteristics were more conducive to our capture methods. Although unsuccessful, we made a substantial amount of effort was made to capture opportunistic fawns from timbered habitats as well.

The 2014-2016 fawning seasons yielded 102 fawns with a skewed sex ratio of 2.1 males to females (Table 2). Peak fawning in our area was May 29, with a 37-day period of confirmed fawn births (e.g. captured with VITs). Average mass of captured fawns was 3.81 kg ± 1.11 kg with no difference between males and females (M = 3.71kg; F = 4.01 kg, p = 0.21). Average hind foot length for all fawns was 25.6 cm ± 1.76 cm with no difference observed between males and females (M = 25.5 cm, F = 25.8 cm; p = 0.51). Average maternal age for VIT does successfully giving birth was 4.5 yrs ± 3.69 yrs and the range of successful dams in our study was 1.5 to 14.5 yrs old. Average maternal weight was 58.3 ± 6.62 kg.

Mortality

We recorded 67 (65.7%) events for 102 radio-collared fawns prior to the start of the archery deer season. Thirty-two fawns were right-censored prior to the start of archery season (2014 = 9, 2015 = 9, 2016 = 14; Figure 2). Twenty of these fawns (62.5%) were censored due to collar detachment when fawns contacted barbed wire fences, 7

(21.8%) collars were found entangled in briars or branches, and 5 (15.6%) were lost to transmitter failure (e.g. lost contact and could not hear via ground or aerial telemetry for remainder of project). Thirty-five of 102 fawns (34.3%) died during this period. Predation events accounted for 13 of 35 of fawn deaths (37.1%; 2014 = 6, 2015 = 5, 2016 = 2; Figure 2), while suspected predation events accounted for 15 of 35 fawn deaths (42.8%; 2014 = 5, 2015 = 3, 2016 = 6; Figure 2). Combined predation and suspected predation events accounted for 28 of 35 deaths (80.0%; 2014 = 11, 2015 = 9, 2016 = 8; Figure 2). The 99 genetic samples we collected during 2014 - 2015 from 30 individual fawns and on-site evidence collected from 2014-2016 indicated only coyotes and bobcats were responsible for predation. Genetic testing indicates that coyotes and bobcats were responsible for up to 61.5% and 38.5% of predation events, respectively. Abandonment accounted for 4 (11.4%; 2014 = 1, 2015 = 3, 2016 = 0; Figure 2) mortalities. Sickle bar hay cutters killed 2 fawns (5.7%; 2014 = 1, 2015 = 1, 2016 = 0; Figure 2), and 2 more fawns (5.7%, 2014 = 1, 2016 = 1; Figure 2) were struck and killed by a vehicle.

Fawn Survival

The best fitting model for predicting 4-month survival for all fawns was the null model (Table 3). The top four models were all ≤ 2 ΔAICc units from one another (Null = 0, Weight = 0.98, Weight + Hind Foot = 1.16, and Year = 1.45). Thus, none of the variables we examined were significant in predicting survival to four months for all of the fawns within our study area. We estimated 4-month survival for all fawns within Clay County at 43% (95% CI: 29 – 57%). Likelihood ratio tests did not detect any difference between years ($X^2 = 0.17$, $p = 0.68$) or sex ($X^2 = 0.33$, $p = 0.85$).

We then investigated the additive potential of maternal variables on survival in VIT fawns by adding maternal weight and age of these known females to the base list of covariates. The best fitting model for predicting survival for the 61 VIT fawns was the null model (Table 4). However, because the top 5 competing models were ≤ 2 ΔAICc units from one another (Null = 0, Maternal Age = 1.06, Hind Foot = 1.39, Year = 1.68, and Weight = 1.99), maternal characteristics were also not significant in predicting 4-month survival. We estimated recruitment into the huntable population at 0.58 fawns/doe.

We also generated survival estimates to eight weeks to allow comparisons with other studies that estimated survival to weaning age. Using CPH models, we estimated 8-week survival conditional to the minimum, mean, and maximum observed birth dates for fawns in our study (Table 5). Fawns in our study that were born at the minimum birth date (May 9) had an estimated survival rate of 48% (95% CI: 31-65%), while fawn survival of those born at the mean birth date (May 30) was 66% (95% CI: 52-80%). Fawns born at the maximum birth date had an estimated survival rate of 93% (95% CI: 97-100%; Figure 3). Because there was no overlap within the confidence limits in any of the estimates, there was statistically significant difference between maximum and mean, and maximum and minimum birth date of fawns based on the confidence intervals in each comparison. There was not a statistically significant difference between minimum and mean birth date fawns (Table 4).

Table 2. White-tailed deer fawn captures by method and sex during the 2014-2016 fawning seasons in Clay County, Kentucky, USA.

Year	Sex	VIT	Opportunistic	Total
2014	Male	13	9	22
	Female	7	6	13
2015	Male	18	4	22
	Female	4	5	9
2016	Male	12	13	25
	Female	8	3	11
	Total	61	41	102

Table 3. Cox proportional hazards (CPH) model selection used to estimate survival (*S*) of 102 radio-monitored white-tailed deer fawns in Clay County, Kentucky, USA (2014-2016). We modeled the following single and additive effects on *S*: Sex, Year, Weight, and Hind Foot Length (HF). Model selection was limited to two effects. The null and top five competing models are presented.

Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]	log[e]
All Fawns					
Null	0	270.4	0.0	0.20	-135.192
Weight	1	271.4	0.98	0.12	-134.664
Weight + HF	2	271.5	1.16	0.11	-133.711
Year	2	271.8	1.45	0.10	-134.897
HF	1	272.4	2.02	0.07	-135.181
Sex	1	272.4	2.04	0.07	-135.191

[a]: Number of model parameters
[b]: Akaike's Information Criterion corrected for small sample size
[c]: Relative difference between AIC_c of model and the highest ranked model
[d]: Model weight
[e]: log Likelihood

Table 4. Cox proportional hazards (CPH) model selection used to estimate survival (*S*) of 61 radio-monitored white-tailed deer fawns caught using vaginal implant transmitter (VITs) in Clay County, Kentucky, USA (2014-2016). We modeled the following single and additive effects on *S*: Sex, Year, Weight, Hind Foot Length (HF), and Maternal Age (MAGE). Model selection was limited to two effects given the relatively low sample size. The null and top five competing models are presented.

Model	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]	log[e]
VIT Fawns					
Null	0	185.3	0.00	0.163	-92.650
MAGE	1	186.4	1.06	0.09	-92.147
HF	1	186.7	1.39	0.08	-92.310
Year	1	187.0	1.68	0.07	-92.457
Weight	1	187.3	1.99	0.06	-92.611
Sex	1	187.4	2.07	0.058	-92.649

[a]: Number of model parameters
[b]: Akaike's Information Criterion corrected for small sample size
[c]: Relative difference between AIC_c of model and the highest ranked model
[d]: Model weight
[e]: log Likelihood

Table 5. Estimated survival rates (S) for white-tailed deer fawns captured in Clay County, Kentucky, USA (2014-2016). We used Cox proportional hazards models (CPHM) to estimate fawning season survival to the onset of the fall archery deer season (May 1-September 7; CPHM 4) for all fawns captured over the three seasons (n=102). In addition, we used CPHM to estimate survival based on the minimum, mean, and maximum observed birth dates to estimate expected survival rates to eight weeks (CPHM Conditional) for all fawns.

Model	*S*	95% CI
CPHM 4		
All fawns	0.43	0.29-0.57
CPHM Conditional		
Minimum	0.50	0.35-0.66
Mean	0.68	0.57-0.79
Maximum	0.95	0.90-1.0

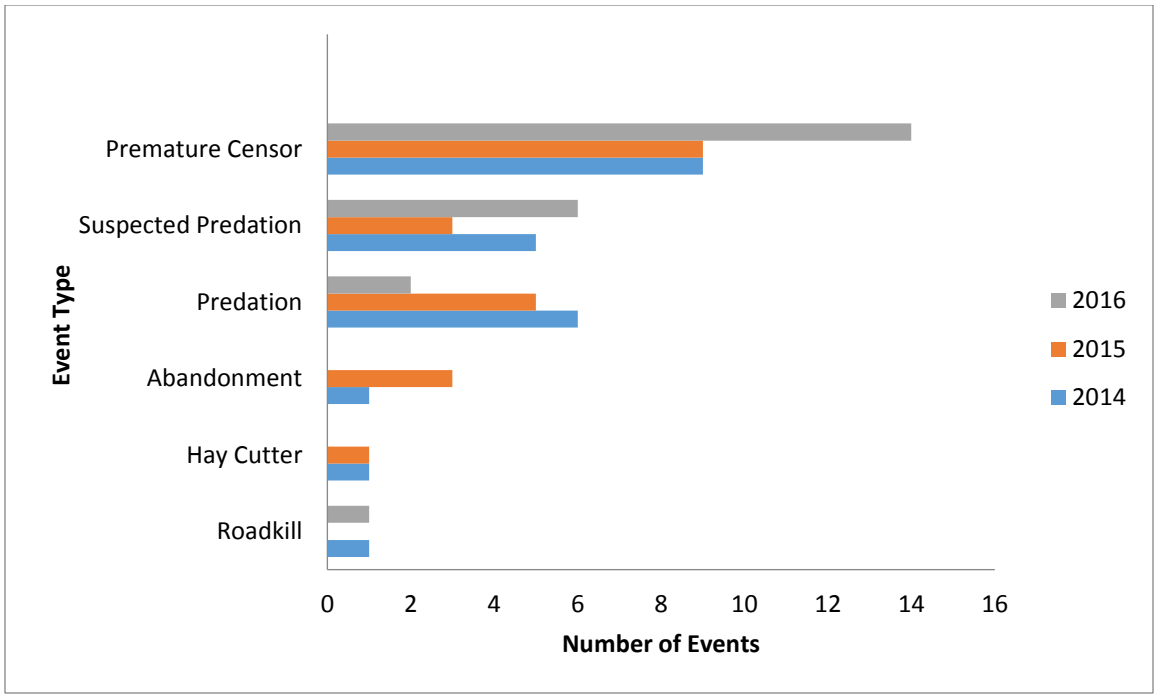

Figure 2. Cause-specific mortality of 102 radio-monitored white-tailed deer fawns at the start of the 2014-2016 fall archery seasons in Clay County, Kentucky, USA.

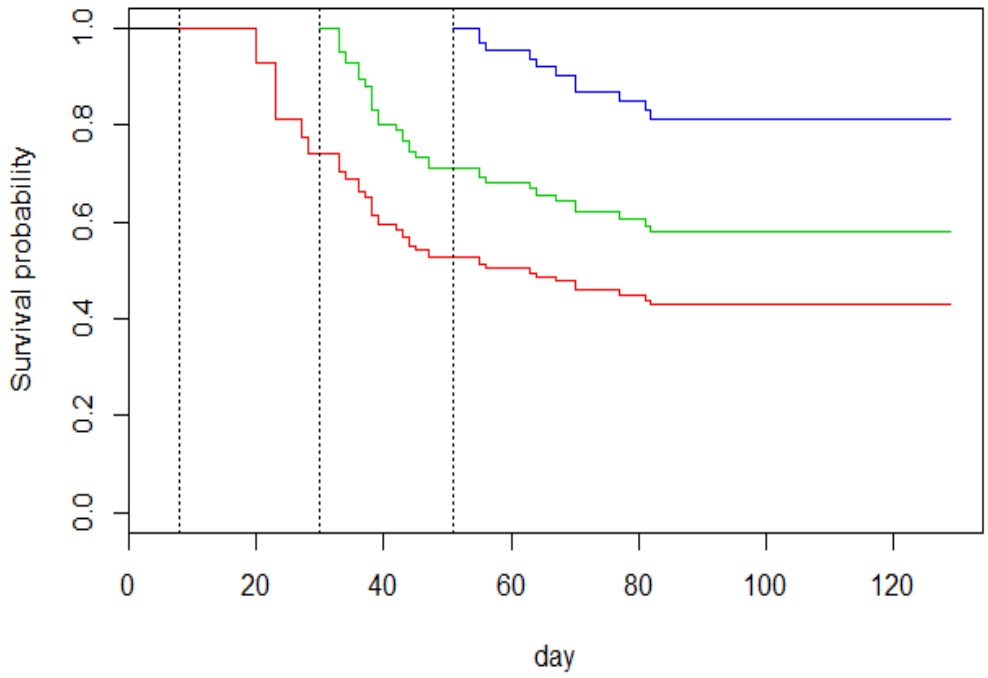

Figure 3. Survival probability (S) conditional on birth date for 102 radio-monitored white-tailed deer fawns captured during the 2014-2016 summer fawning seasons in Clay County, Kentucky, USA. We used Cox proportional hazards models (CPHM) to generate a range of eight-week survival estimates based on the minimum, mean, and maximum birth dates (denoted by hashed vertical lines) observed through the use of vaginal implant transmitters (VITs). Lines of the same color represent fawns born at the same time period x.

Discussion

Understanding the relationship between animal productivity and factors influencing population dynamics is critical for adopting measures that best informs single species management (Robinson et al. 2014). Managers should have an understanding of how neonate mortality (and subsequent survival and recruitment) influences the local deer populations in their areas prior to hunting season (Rosenberry et al. 2011) because life history parameters of local populations are not always homogenous in space. Variations in local resource availability may exist at both large and small spatial scales, which may affect certain demographic rates (e.g. neonate survival) of a population (Coulson et al. 1999). In supposedly poorer-quality, mast-driven habitats within the central Appalachians, local resource availability may have the potential to indirectly influence neonate survival at smaller spatial scales through natural mast production cycles.

Survival

The 4-month survival estimate of fawns (43%) in our study was higher than we hypothesized; this was surprising because southeastern Kentucky has been considered to be of comparatively poorer habitat quality than other deer-occupied areas in the state, and because of local sympatry with coyotes, bobcats, and domestic dogs. Fawn survival in southeastern Kentucky was higher than documented rates from many southeastern states, but lower than many estimates presented in the Midwest and more northern areas (Table 6). Outside of the recent paper by McCoy et al. (2013), most of the fawn studies that present a low survival estimate are within the southeastern U.S., while many of the higher

estimates are in northern and Midwestern states. With the exception of Vreeland et al. (2004), fawn survival estimates are lacking within central Appalachia.

Conditional survival estimates in our study suggest that fawns born later in the season have a greater chance of survival to weaning than fawns born at the beginning or peak (Figure 2). This is contrary to the predator swamping theory which suggests: a) that fawns have a higher chance of survival when born earlier in the season or at peak fawning, b) early season fawns are able to reach "fleeing size" before predators develop a hunting image and become more experienced in capturing prey, c) fawns born with many cohorts have higher survival odds because predators are overwhelmed by prey numbers and often satiated, and d) fawns born later in the season should experience higher mortality risk because they are less developed and their birth coincides with more experienced predators (Testa 2002). This top-down selection by predators should regulate the synchrony of birthing events, and it is interesting that our results were contrary to this theory, especially since predation by bobcats and coyotes were a prevalent mortality source. Vreeland et al. (2004) in Pennsylvania observed an opposite reaction; they were unable to detect any difference between fawns born at the median birth date and those born at the peak. In our study, we believe the high number of fawns already on the landscape may have allowed later-born fawns to have a greater chance of eight-week survival than fawns born at other periods.

Other explanations for the conditional survival estimates generated from our dataset may exist. Although Kentucky does not currently possess any long-term trend data on coyote or bobcat densities, it is plausible that our study area has a relatively low predator density, or at least low enough to where it isn't impacting the life history

birthing strategy (e.g. synchrony of births) of deer at the population level. In other words, predators within this particular portion of Clay County may not exist in sufficient numbers to shift the peak fawning period to later in the season when we have documented higher survival. Another possible explanation could be some form of prey switching by predators during the fawning season. Although deer fawns are abundant during the fawning season, it may be more energetically efficient or easier to hunt smaller prey sources such as eastern cottontails (*Syvilagus floridanus*), squirrels (*Sciurus sp.*), voles (*Microtus sp.*), and mice (*Mus sp.*). We also observed multiple years of high mast crop availability within the study period, which subsequently may have caused an increase in rodent species that were easier prey sources for bobcats and coyotes. Another potential food-related explanation for the differences in 8-week survival estimates is the seasonal food availability. Cox (2003) reported finding grasshoppers and fruit in summer coyote scats in eastern Kentucky. It is possible that the maximum birth date fawns could have experienced higher survival because there was a higher availability of seasonal fruits for coyotes to consume when these fawns were being born. A final explanation that could serve to aid our understanding of the conditional survival estimates is a relatively low sample size in each observational period (e.g. minimum, mean, maximum observed birth dates).

Because nearly all of the opportunistic fawns were >1-day old, comparisons between this group and VIT fawns (<1-day old) could be biased because the former had already survived an initial high-risk post-parturition mortality period that occurs during the first 24 hrs. (Kilgo et al. 2012). Consequently, it is likely that previous fawn studies that rely on opportunistic captures of fawns ≥ one day are potentially overestimating

survival (Kilgo et al. 2012). In an effort to eliminate this overestimation, we elected to use CPH models because they remove a lot of the bias associated with age at capture differences (Riggs and Pollock 1992). The model also includes a fawn the day it was captured and estimates generated with these models are considered appropriate as long as the proportional hazards are constant through time (Farmer et al. 2006), which they were in our analysis.

Mortality Sources

Predation, including suspected predation events, accounted for 80% of all mortalities in our study area, which is within the range of commonly reported rates throughout many deer fawn studies (Table 6). Based on field evidence and mtDNA analysis from the 2014 and 2015 seasons, coyotes and bobcats were responsible for the entirety (61.5% and 38.5%, respectively) of the predation component (including suspected predation events where mtDNA samples were submitted) of mortalities in our study. We did not misidentify any predator saliva samples that were sent for analysis. For example, when physical evidence observed during the mortality investigation suggested the predator was a coyote, and we submitted a valid mtDNA sample, the result was always "coyote."

Where present, coyotes often contribute significantly to deer fawn mortality, especially as they have expanded into vacant range (Saalfeld and Ditchkoff 2007). Where they have recently established, coyotes may even be an additive source of mortality (Kilgo et al. 2012). In Kentucky, coyotes have become established over the last 50 years, and Cox (2003) reported finding deer remains in approximately 32% of coyote scats

(almost all of which occurred during fawning and hunting seasons) within our study area. This would suggest that coyotes have played at least a minimal role in fawn mortalities for some time now, although we are unsure how these data would compare to what occurred within the timeframe of our study. However, the singular fact that coyotes have been present on the landscape for five decades does not allow us to determine whether their presence reflects additive or compensatory mortality in the neonate component of this population. When discussing whether the addition of one or more mortality risks (e.g. the presence of coyotes) is compensatory or additive, there are sometimes conflicting definitions that impede our understanding (Zager and Beecham 2006). For example, Zager and Beecham (2006) maintain that mortality is additive when that animal may otherwise live to reproduce, but compensatory if it is likely to die from other density-dependent causes. However, Creel (2011) suggests that additive mortality occurs whenever predation-driven mortality results in an increase of the total population's (or in this case, the neonate demographic of the population) death rate, while compensatory mortality occurs when predation-driven mortality is compensated for by other density-dependent factors. If we were to use the definition provided by Zager and Beecham (2006), then it is highly probable that at least some of the coyote predation we witnessed could be additive, but the same could also be argued for nearly any other mortality factor that was observed. We do not have a comprehensive understanding of prevalent background density-dependent factors that may otherwise contribute to fawn mortality since this particular population was undergoing active restoration efforts thru 1999. Additional longer-term research is needed to fully address and understand the concept of additive or compensatory mortality in our study area. Predator removal studies have

sometimes helped to understand the relative role of predation in prey population dynamics (VanGilder et al. 2009), and our study could serve as a baseline for future research.

Based on previous reports and studies of deer in the area (Phillips 1984, Pais 1987), we hypothesized that feral dogs would likely be a significant mortality factor; however, we did not observe any fawn mortality from dogs. Previous research suggested that dogs have contributed to stunting the growth of translocated deer populations in eastern Kentucky. DeLime (1951) blamed feral dogs for the failure of some of the earliest deer restoration efforts in southeastern Kentucky, and Phillips (1984) claimed that up to 16% of all deaths of translocated deer were attributable to dogs. Likewise, Pais (1987) reported that 55.5% (5 of 9) of all mortalities were attributed to feral or domestic dogs in a radio-monitored sample of translocated deer in southeastern Kentucky. However, 80% (4 of 5) of the deaths attributed to dogs occurred within the first 32 days of the translocation, and it is probable that a myriad of other factors could have led to those deaths including capture myopathy, unfamiliarity with escape routes in a new environment, or other stress-related factors associated with capture and translocation. Although none of the previous studies that reported dogs killing deer made any mention of fawns, it is reasonable to assume that dogs could have contributed to fawn mortality if the adults were being affected.

Prior to the arrival and establishment of coyotes, and in the absence of historical apex predators (e.g. mountain lion [*Puma concolor*] and wolves), bobcats were often the leading cause of predation-related fawn mortalities in the southeastern U.S. (Jackson and Ditchkoff 2013). Bobcats were responsible for up to 38.5% of all predator mortalities in

our study. Roberts and Crimmins (2010) estimated that Kentucky had a bobcat population of approximately 14,000 individuals. In an area of Pennsylvania with somewhat similar habitat characteristics and a bobcat population estimate of 18,766 (Roberts and Crimmins 2010), Vreeland et al. (2004) only reported 7.3% of all fawn mortalities attributable to bobcats. However, Pennsylvania has a much larger bear population than Kentucky, so it is uncertain how the two areas (PA and KY) may have compared with similar bear densities. In Minnesota, Carstensen et al. (2009) listed predation as the cause of 86% of all fawn mortalities, with black bears and bobcats comprising most all of those mortalities. For moose (*Alces alces*) and elk, bears have accounted for between 58-100% and 44-98% of all calf mortalities, respectively (Zager and Beecham 2006). In an experimentally released population of elk in the relatively close Great Smokey Mountain National Park, bears were the predominant source of elk calf mortality, even threatening the long-term viability of the population in the absence of predator control (Murrow et al. 2009). Interestingly, bears accounted for no fawn mortalities in our study which was surprising given the increased sightings in the study area (Will Bowling, KDFWR, personal communication) and the expanding population in southeastern Kentucky (Hast 2010, Murphy et al. 2015). As bear populations in Kentucky continue to expand westward, it will be important to continue to monitor neonate survival of both white-tailed deer and elk.

Aside from predation, abandonment is often the second leading cause of mortality in many fawn studies (e.g. 29.1%, Chitwood et al. 2015; 8%, Rohm et al. 2007). We found that abandonment accounted for 10.8% of all mortalities in our study area. Abandonment is likely a lesser mortality factor of fawns where predators occur. As

neonates become hungrier, they have a tendency to vocalize more frequently which may contribute to increased instances of predation (Chitwood et al. 2014). In fact, we recorded a single instance of a fawn vocalizing frequently when we assumed it had been abandoned. Further, it is oftentimes difficult to determine whether or not fawns were preyed upon due to the increased vocalizations because there are fewer remains from emaciated fawn (i.e. hungrier) carcasses (Chitwood et al. 2015). Based on our sampling techniques, and the generally low risk of marking-induced abandonment in deer fawns, we do not believe that we influenced any fawn abandonment (Powell et al. 2005; Haskell et al. 2007). We also only placed VITs into healthy appearing does to minimize the risk of abortion or predispose fawns to abandonment if the doe was in poor condition. Despite our precautions, several months had passed since many of the does were captured and handled, so it is possible that a doe could have become ill or had pre-existing conditions that were undetectable at capture. Half (n=2) of the abandonment events came from ≤ 3.5-year-old mothers, which may have had some influence since younger mothers are thought to result in higher rates of abandonment. The other two abandoned individuals were from non-known females so it is unknown what potentially influenced the abandonment of their fawns.

Table 6. Comparison of survival estimates and predominant mortality sources of white-tailed deer fawns captured throughout much of the middle-to-eastern portions of the United States.

Authors	Location	4-month Survival	Predominant Mortality Source (and Percent)
Pusateri-Burroughs et al. 2006	Michigan	90-91%	Vehicle Collisions; 29%
Grovenburg et al. 2012	South Dakota	54 - 94%	Predation; 52%
Nelson and Woolf 1987	Illinois	*70%	Predation; 69%
McCoy et al. 2013	South Carolina (coastal)	67.6%	Predation; 42.6%
Vreeland et al. 2004	Pennsylvania	48.6%	Predation; 46%
Carstensen et al. 2009	Minnesota	*47%	Predation; 86%
McDermott (this study)	Kentucky	43%	Predation; 80% (including suspected mortalities)
Saalfeld and Ditchkoff 2007	Alabama	*33%	Predation; 41%
Nelson et al. 2015	Georgia	29%	Predation; 76.2%
Kilgo et al. 2013	South Carolina	23%	Predation; 88.6% (including probable mortalities)
Chitwood et al. 2015	North Carolina	14%	Predation; 64%
Ricca et al. 2002	Oregon	*14%	Predation; 57%

* Denotes a survival estimate ≠ 4 months

Management Implications

Our study establishes a benchmark to assess fawn survival trends and implications for deer population dynamics in an area where long-term population decline is suspected. We considered fawn survival in southeastern Kentucky to be moderately low, but comparable with other studies in the eastern U.S. Predation by coyotes and bobcats were the leading causes of mortality, but other anthropogenic factors did influence survival. The recent colonization of coyotes into this region may have decreased fawn survival and subsequent recruitment, but in the absence of similar prior studies, we cannot state that coyote predation is additive to prior to their arrival in the mid-twentieth century. Periodic monitoring of fawn survival will be needed to inform models examining long-term deer population trends, and to account for potential new mortality factors, such as the projected population growth of predators including the black bear and bobcat. Although recruitment is an important metric used to inform population models, retention of ungulate neonate collars through reproductive age is problematic because of rapid changes in neck size. A collar needs to be constructed of material that expands with developmental increases in neck size but durable enough to be retained. In our study, a disproportionally high number of individuals had to be right-censored from our models as fawn collars were lost from entanglement in barbed wire fence or briars. Consequently, we were unable to estimate fawn survival to reproductive age due to loss of statistical power. We suggest that collar manufacturers investigate new designs that allow for expansion as a fawn gets older, but are also constructed of a material that will not be so easily snared during fawn movement. In areas with known fawn collar snaring hazards, it

may be prudent to investigate the use of recently developed mammalian rumen implants (ATS 2015).

Appendix 1. White-tailed deer fawn data collected during the 2014-2016 summer fawning seasons in Clay County, Kentucky, USA. Included are: Fawn ID (plastic/metal ear tags), capture date, event data, fate, sex, hind foot length, weight, age at capture, and maternal characteristics. Only fawns captured with VITs have maternal attributes shown in the table, and an N/A symbol in the maternal weight category signifies that we were unable to record her weight due to capture difficulties.

Fawn ID	Capture Date	Event Date	Fate	Sex	Hind Foot(cm)	Weight(kg)	Age at Capture	Maternal Age	Maternal Weight(kg)
079/ 13884	5/9/2014	5/21/2014	Abandonment	Female	25.08	3.52	1	2.5	N/A
085/ 13880	5/9/2014	6/17/2014	Censor	Female	25.08	2.95	1	2.5	N/A
118/ 13743	5/18/2014	6/19/2014	Censor	Male	27.31	3.86	1	3.5	63.64
106/ 13877	5/18/2014	9/7/2014	Recruited	Female	24.45	2.95	1	7.5	55.45
107/ 13745	5/18/2014	9/7/2014	Recruited	Male	25.72	3.44	1	3.5	63.64
111/ 13747	5/18/2014	9/7/2014	Recruited	Male	25.40	3.32	1	7.5	55.45
117/ 13734	5/19/2014	7/14/2014	Censor	Female	22.86	3.52	1	2.5	55.45
121/ 13737	5/19/2014	7/14/2014	Censor	Male	23.50	2.97	1	2.5	55.45
096/ 13892	5/26/2014	6/8/2014	Predation	Female	26.67	3.14	1	1.5	64.55
124/ 13876	5/26/2014	6/8/2014	Predation	Male	27.94	3.64	1	1.5	64.55
078/ 13889	5/26/2014	6/9/2014	Predation	Male	26.04	3.83	2	3.5	57.73

108/ 13748	5/28/2014	6/13/2014	Predation	Male	26.67	3.64	2	3.5	49.09
102/ 13732	5/29/2014	6/29/2014	Censor	Female	23.18	2.53	1	3.5	48.64
112/ 13878	5/29/2014	7/8/2014	Censor	Male	23.18	2.50	1	3.5	48.64
099/ 13894	6/2/2014	6/4/2014	Predation	Male	24.13	2.84	1	6.5	64.55
115/ 13740	6/2/2014	7/17/2014	Predation	Male	27.94	5.25	14	-	-
084/ 13888	6/3/2014	9/7/2014	Recruited	Male	26.67	3.55	4	-	-
113/ 13835	6/3/2014	9/7/2014	Recruited	Male	28.26	5.99	14	-	-
090/ 13897	6/3/2014	9/7/2014	Recruited	Female	27.94	5.68	15	-	-
082/ 13885	6/4/2014	7/10/2014	Predation	Male	23.02	2.78	7	-	-
083/ 13890	6/5/2014	6/9/2014	Predation	Female	26.35	3.61	1	10.5	61.36
088/ 13893	6/5/2014	7/21/2014	Predation	Male	26.99	3.89	1	-	-
097/ 13895	6/8/2014	6/17/2014	Hay Cutter	Male	27.94	5.00	5	-	-
123/ 13742	6/8/2014	8/25/2014	Censor	Female	30.16	8.04	16	-	-
076/ 13887	6/8/2014	9/7/2014	Recruited	Male	28.58	5.68	5	-	-

092/ 13900	6/9/2014	6/12/2014	Predation	Male	24.77	3.13	1	1.5	55.45
091/ 13891	6/9/2014	6/14/2014	Predation	Male	24.13	3.01	1	1.5	55.45
094/ 13896	6/9/2014	7/3/2014	Roadkill	Female	27.62	6.11	8	-	-
095/ 13899	6/11/2014	9/2/2014	Censor	Female	26.04	4.77	4	-	-
122/ 13736	6/11/2014	9/7/2014	Recruited	Male	24.77	2.81	1	-	-
100/ 13898	6/12/2014	7/22/2014	Predation	Male	25.40	3.35	1	3.5	50.91
116/ 13739	6/12/2014	9/7/2014	Recruited	Male	25.08	2.87	1	3.5	50.91
119/ 13733	6/13/2014	6/26/2014	Censor	Female	27.94	4.52	1	-	-
120/ 13741	6/17/2014	9/7/2014	Recruited	Male	28.58	5.14	9	-	-
103/ 13744	6/21/2014	9/7/2014	Recruited	Female	29.21	5.85	10	-	-
089/ 13852	5/15/2015	5/24/2015	Predation	Male	24.13	2.90	1	6.5	65
134/13859	5/15/2015	5/27/2015	Censor	Female	24.13	3.10	1	6.5	65
135/13860	5/15/2015	6/7/2015	Predation	Male	23.50	3.18	1	11.5	60.45
141/13838	5/20/2015	5/24/2015	Abandonment	Female	24.77	3.24	1	1.5	55.45

086/13882	5/20/2015	5/29/2015	Predation	Male	25.40	3.75	1	1.5	55.45
143/13840	5/21/2015	6/24/2015	Censor	Male	25.72	3.86	1	7.5	70.45
150/13845	5/22/2015	6/14/2015	Predation	Female	24.77	3.55	1	3.5	55.45
136/13861	5/22/2015	9/7/2015	Recruited	Male	27.31	4.43	1	13.5	67.27
093/13801	5/24/2015	9/7/2015	Recruited	Male	26.67	4.15	1	6.5	54.55
145/13842	5/25/2015	5/28/2015	Abandonment	Female	23.18	2.24	1	-	-
13865	5/26/2015	6/27/2015	Censor	Male	23.50	3.07	1	-	-
139/13836	5/26/2015	7/16/2015	Censor	Male	25.40	3.21	1	2.5	64.55
129/13850	5/26/2015	9/7/2015	Recruited	Male	24.77	3.04	1	2.5	64.55
13867	5/29/2015	6/3/2015	Predation	Male	24.13	3.04	1	2.5	N/A
13871	5/29/2015	9/7/2015	Recruited	Male	25.08	3.30	1	2.5	N/A
080/ 13886	5/30/2015	9/7/2015	Recruited	Male	26.04	3.47	1	3.5	N/A
087/ 13851	6/1/2015	9/7/2015	Recruited	Female	27.62	5.54	9	-	-
126/13846	6/2/2015	7/1/2015	Censor	Female	26.99	5.11	5	-	-

142/13839	6/4/2015	6/15/2015	Predation	Female	25.40	3.18	1	1.5	58.18
125/13746	6/5/2015	6/7/2015	Censor	Male	25.40	3.07	1	2.5	59.09
13809	6/5/2015	6/13/2015	Hay Cutter	Male	24.45	2.81	1	1.5	56.82
131/13857	6/5/2015	6/14/2015	Censor	Male	25.08	2.76	1	2.5	59.09
13868	6/5/2015	9/7/2015	Recruited	Male	21.59	2.13	1	1.5	56.82
127/ 13847	6/6/2015	8/4/2015	Censor	Male	23.81	2.98	1	-	-
130/13849	6/6/2015	9/7/2015	Recruited	Male	22.54	2.16	10	-	-
13807	6/7/2015	6/8/2015	Abandonment	Female	25.08	2.78	6	-	-
140/13837	6/7/2015	7/13/2015	Censor	Male	28.58	6.16	16	-	-
13869	6/9/2015	9/7/2015	Recruited	Male	24.13	3.24	1	5.5	61.82
13873	6/9/2015	9/7/2015	Recruited	Male	24.45	3.41	1	5.5	61.82
13813	6/9/2015	9/7/2015	Recruited	Female	26.04	3.89	4	-	-
133/13856	6/15/2015	6/25/2015	Predation	Male	26.67	3.69	1	1.5	46.82
239/13815	5/18/2016	6/6/2016	Censor	Female	24.45	3.24	1	4.5	54.55

258/14582	5/27/2016	6/26/2016	Predation	Male	25.40	3.36	1	3.5	54.55
270/14580	5/29/2016	6/25/2016	Predation	Male	24.77	3.38	1	4.5	54.55
266/14557	5/29/2016	9/7/2016	Recruited	Female	23.81	3.49	1	4.5	54.55
197/13862	5/29/2016	9/7/2016	Recruited	Male	24.77	3.30	1	2.5	63.64
254/14561	5/29/2016	8/5/2016	Censor	Female	25.40	3.38	1	2.5	63.64
259/14579	5/31/2016	7/21/2016	Censor	Female	26.04	3.30	1	2.5	N/A
256/14563	6/1/2016	6/6/2016	Predation	Male	26.99	4.26	6	-	-
268/14555	6/1/2016	7/4/2016	Predation	Male	21.59	2.86	1	1.5	47.73
265/14575	6/2/2016	6/6/2016	Predation	Male	25.72	3.47	1	7.5	N/A
269/14556	6/2/2016	6/3/2016	Predation	Male	24.13	3.15	1	7.5	N/A
257/14581	6/2/2016	6/19/2016	Censor	Male	26.35	3.86	4	-	-
263/14553	6/2/2016	6/7/2016	Censor	Female	26.35	3.98	4	-	-
264/14576	6/3/2016	6/23/2016	Censor	Female	25.40	4.15	6	-	-
148/13843	6/3/2016	9/7/2016	Recruited	Male	22.86	2.78	1	14.5	74.09

149/13844	6/3/2016	7/22/2016	Censor	Male	25.72	3.82	1	14.5	74.09
128/13848	6/4/2016	9/7/2016	Recruited	Female	25.40	3.95	1	1.5	45.45
252/14559	6/5/2016	9/7/2016	Recruited	Male	24.45	2.84	1	2.5	N/A
77/13883	6/5/2016	9/7/2016	Recruited	Male	24.13	2.93	1	2.5	N/A
242/13818	6/7/2016	9/7/2016	Recruited	Male	28.89	5.65	10	-	-
253/14560	6/8/2016	7/2/2016	Censor	Male	30.16	7.09	12	-	-
200/13814	6/8/2016	6/14/2016	Censor	Male	25.40	3.61	2	-	-
180/13881	6/8/2016	6/10/2016	Censor	Male	27.94	4.26	6	-	-
230/13864	6/10/2016	6/17/2016	Predation	Female	25.40	3.60	1	6.5	61.82
196/13808	6/10/2016	9/7/2016	Recruited	Female	25.72	3.60	1	6.5	61.82
238/13817	6/10/2016	7/1/2016	Censor	Male	26.67	5.57	10	-	-
195/13866	6/10/2016	9/7/2016	Recruited	Male	24.45	2.93	1	2.5	N/A
199/13870	6/10/2016	8/19/2016	Censor	Male	25.08	3.72	1	2.5	N/A
144/13820	6/11/2016	9/7/2016	Recruited	Male	25.08	3.89	4	-	-

137/13863	6/12/2016	9/7/2016	Recruited	Male	25.08	4.23	6	-	-
241/13872	6/13/2016	9/7/2016	Recruited	Male	24.13	3.64	3	-	-
235/13874	6/15/2016	8/5/2016	Censor	Female	26.99	6.02	10	-	-
243/13819	6/15/2016	7/7/2016	Predation	Male	28.58	6.15	11	-	-
246/13820	6/16/2016	9/7/2016	Recruited	Male	27.94	5.56	10	-	-
234/13816	6/16/2016	7/10/2016	Roadkill	Female	25.72	4.18	1	6.5	52.27
198/13812	6/18/2016	7/6/2016	Censor	Male	26.04	4.29	7	-	-

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